The Study Of Noncorona High Temperature Electrostatic Precipitation

Author(s): C. Aizhu, W. Qidong, Z. Jingsheng, W. Yanhua, and G. Xianzhao

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Chen Aizhu, Wei Qidong, Zhou Jinsheng, Wu Yanhua and Guo Xianzhao

Thermoenergy Engineering Research Institute, Southeast University, Nanjing, China

Abstract

Noncorona high temperatare electrostatic precipitation (NHTEP) utilizes some materials which have good propertices of heat emission to fabricate electrodes, so as to make the dust particles charged at high temperature. The charged particles are caught, which is caused by the effect of the electric field force, thus the dusty gas can be clarified.

Because of using gaseous thermal energy itself, the NHTEP suits specially to clarify the high temperature flue gas for gas–steam combined cycle, MHD–steam combined cycle generation, and coal gasification, etc.

The primary results of our experimental research and calculation show that NHTEP has the characteristics of corona electrostatic precipitation. In addition, it also has many advantages of the structure simple, the volume small, the emitting current density larger, the control easy and the electric field stronger and well distributed.

1.Introduce

Electrostatic precipitation was used widely, because of its high efficiency, low resistance and large capability of removing dust. But so far, the electrostatic precipitators are all based on the corona emission, requiring a cathode with special structure which can cause an extremely non–uniform electric field so that the corona can be started up. The precipitation efficiency is greatly dependent on the maximum electric field that can be applied without both the sparkover and the onset of back corona. However, under the high temperatuer and the atmosphere,the difference between the voltage of the sparkover and that of the starting up corona is so small that the range of its operation is very narrow. Under the atmosphere, the highest operating temperature of corona electrostatic precipitator (ESP) is about 350℃ ~ 400℃. It can not meet the needs for many engineering aspects, such as MHD–Steam combined cycle generation, coal gasification and gas–steam combined cycle generation, etc. in which the high temperature dusty gas needs to be cleaned.

It is well known that every substance has the active energy itself. when heated to enough high temperature, the substance will have capability of emitting free electron. According to this principle, an idea had been put forward to use the cathode emission as an electron source of the electrostatic precipitation, and many static tests on heat emitting characteristics of various materials in the atmosphere condition were done in 1985, and some materials of lower ionizing potential have been obtained. The emitting current is of the order of one or two more than that of ESP[2]. The relationship between the emitting current density and the temperature is shown in Figure 1.

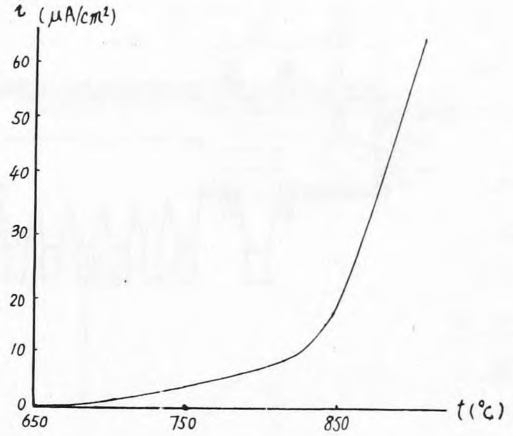


Figure 1.The relationship between emitting current and temperature.

Based on these static tests, the research and development of the NHTEP have been carried out since 1986. At first, we did investigations of NHTEP of both single–stage and two–stage with emphasis on the later.

In charged section of the two–stage precipitator, when the cathode is heated to enough high temperatuer, the emission of electron will occur. Then, the dust particles are charged and the charged particles are caught in the collection section When the extra voltage on the electrode in the charged section is lower than that in the collection one, the two–stage NHTEP can also be operated stably. In addition, a special structure of cathode appears to be necessary in collection section no longer. Therefore, the problem about insulation at high temperature can be solved easily. Its extra electric field in the collection section is stronger than that of ESP and well distributed. The voltage of the collection section is 10500v(E = 300kv / m)without the sparkover at the temperature 600℃ and the atmosphere pressure. As compared with ESP, when collection efficiency of both ESP and NHTEP is the same, the NHTEP has many advantages, for instance, its collection section becomes shorter, the structure gets more compact and its cost is lower.

2.Structure Design

Because the dust particles removed as well as charged are in the same place of the single–stage NHTEP, the actual length of the collection section will become longer and it is necessary to add a great high voltage to all section. As a result, the structure of single–stage NHTEP becomes complicated and the dust charged is cleaned away with more difficulty.

The two–stage NHTEP consists of the high temperature generator, the charging section, the removing dust section and the dust bin, etc. The all components are connected with flages so as to have advantages of installation, adjustment, experiment and maintenance. The schematic diagram of the equipment is shown in Figure 2.The emitter in the charged section is heated both inside and outside simultaneously. There is a dust bin in the charged section and there are six dust bins in the collection one. This structure is beneficial to the measurement of the properties for the precipitator.

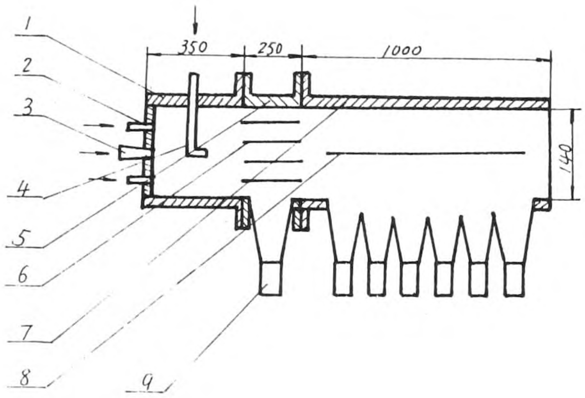


Figure 2.The schematic diagram of the NHTEP
1.combustor; 2.air entrance; 3.nozzle for burning
4.dust inlet; 5.charged section; 6.emitter
7.cathode; 8.collection section; 9.dust bin

main design parameters
cross area of precipitator $70 \times 140mm^2$
velocity of gas in the electrical field 0.8~ 1.2m / s
size of the parallel plate electrode
(cathode) $900 \times 80mm \times mm$
actual length of electrical field 960mm
distance between cathode and anode 35mm
size of the emitter $120 \times 110mm \times mm$
operating temperature of the equipment
lower than 1100℃
the most operating voltage of the equipment
30000V at environmental temperature
10500V at the temperature 600℃
6000V at the temperature 500℃
removing the dust efficiency more than 90%
The dust used is provided by the Power Station Xiaguan, NanJing.
The characters of the dust are as follows:
medium diameter $d_{50} = 24.3\mu m$
true specific weight $2.12g / cm^3$

The dispersity of the dust is given by Table 1.

Table 1.Dispersity of the dust measured by the method of Bark Centrifugal Classification

diameter of dust particle μm	<2	2~5	5~8	8~10	10~20	20~30	>30
wt. %	0.3	3.8	6.0	5.1	25.7	16.5	41.7

A relation plot of the dust mass resistivity against the temperature is shown in Figure 3.

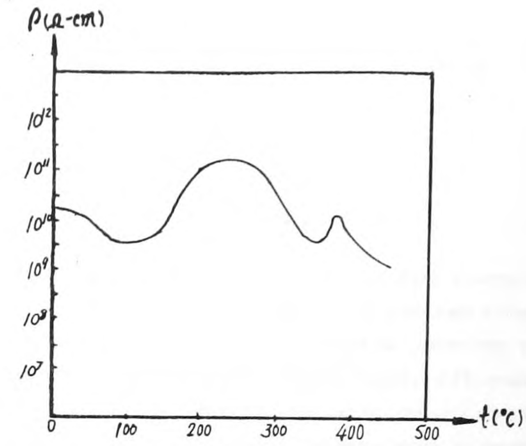


Figure 3.The variation of the specific massive resistivity of the dust vs the temperature

3.The experimental results and the theoretical analyses

3.1.The mechanism to make the dust particles charged

To make dust particles charged is one of the main processes of precipitation. There are two mechanisms in the charging pass. One is electric field charging and the other diffusion charging. The later is principle for a two–stage NHTEP, because the extra voltage on the two–stage NHTEP is lower and the electric field is weaker. On the other hand, the temperature is higher and the heat velocities of electrons, ions and dust particles are greater. This view has been proved by the results of theoretical calculation. The charge quantity of electric field charging and that of diffusion charging are taken into account by the following two equations respectively[1].

$$q_s = 12\pi a^2 q_0 \cdot E_0 \tag{1}$$

$$q = \frac{akT}{e} ln(1 + \frac{\pi a \overline{V} N_0 e^2 t}{kT}) \tag{2}$$

here q_s--charge quantity of electrical field charging,c;
a--diameter of dust particle,m;
q_0--electric constance
$q_0 = 8.85 \times 10^{-2} c / v \cdot m$;
E_0--electric field strength,v / m';
q--charge quantity of diffusion charging,c;
k--Boltzman constance,J / k;
e--electron charge number,c;
T--the gas temperature,K;
t--the time of the dust particle passing through the charged section with gas flow,s;

$$t = \frac{H}{V_s}$$

H--the length of the charging section ,m ;

V_0--the velocity of the core gas flow in inlet , m / s ;

N_0--average numbers of charged particles in the unit volum ,Numbers / m^3;

$\bar{V}$--a root-mean square of ionic heat velocity ,m / s ;

The calculation results are listed in Table 2 ,and it shows that charge quantity of diffusion charging is of the order of one or two more than that of electric field charging .Therefor ,electric field charging can be neglected.

Table 2 Calculating value of the charge quantity

charge type / particles diameter μm	q_s c	q c
0.5	1.19×10^{-18}	1.13×10^{-16}
5	1.19×10^{-16}	1.55×10^{-15}
9	3.86×10^{-16}	2.63×10^{-15}

3.2 V-I Characteristic

As mentioned above ,the electrons are produced by the heat emission of the substance in the NHTEP. The electrons can not escape from the surface of body at the environmental temperature. While heated, the energy of electrons of the substance increases quickly because of thermal movement of its molecules. When the energy is more than the surface free energy, the electrons will escape from the surface of body .These escaped electrons will form electron cloud near the emitter, which is called the space charge. If a conductor (anode) is seted near the emitter, when its voltage is higher than that of the emitter and a difference of the electric potential is kept, the electrons will stably migrate from the emitter to the anode, thus, an emitting current is formed. The value of the emitting current relates to the temperature as well as the voltage. The relations of the emitting current against the temperature and the voltage are shown in Figure 4. and 5. respectively. It is shown from Figure 4.that,if the voltage is not changed, the emitting current will increase with the temperature.It has been conformed by the results of many static tests. When the temperature is constant, the emitting current increases with the extra voltage in the charging section, but when the voltage increases to a certain value, the emitting current approachs to a constant. Figure 6 is a.model V-I curve. To compare Figure 5 with Figure 6, we can find that the emitting characters of the emitter studied agree with the heat emitting theory.

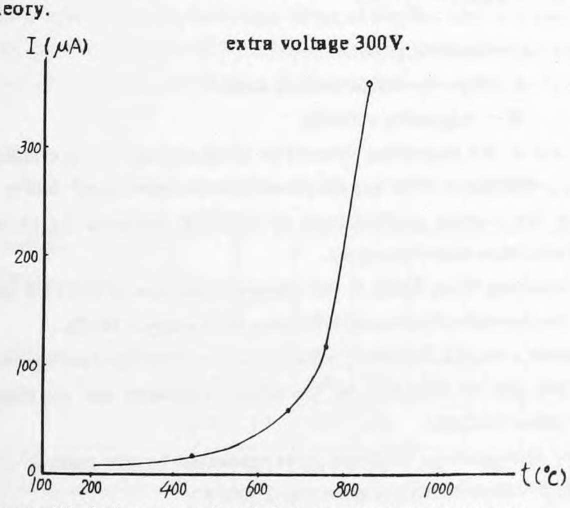


Figure 4 Relation plot of emitting current vs temperature.

temperature of emitter T = 850℃

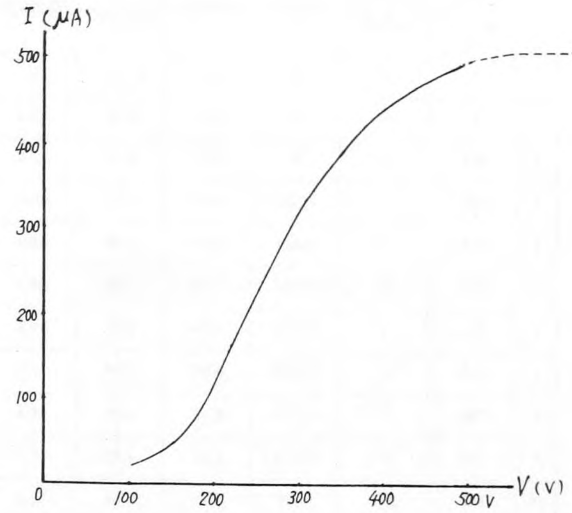


Figure5.Relation of emitting current vs voltage

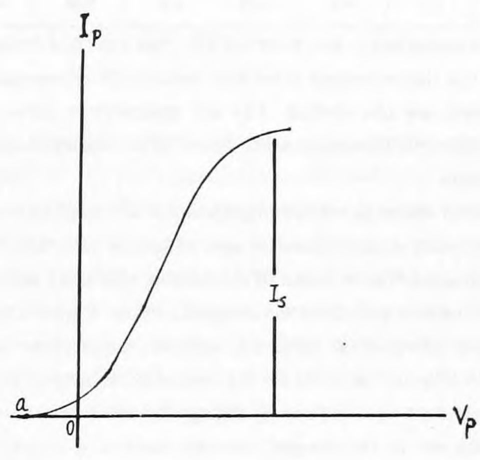


Figure 6. The model V-I curve

3.3 Duster character

Because the dusting mechnism of eletrostatic precipitator is very complex and there are a lot of the factors of influencing precipitation efficiency, therefore,it is imposible to use only theoretical calculation for industrial design ,but necessary to lay stress on the experimental research. Thus, based on the single-stage NHTEP, an experimental equipment of two-stage NHTEP was set up and many experimental researchs on it were completed, including the natural deposition of dust particles, variation of dusting efficiency against temperature in charging section and the variation of the dusting efficiency against the voltage in the collection section, etc. The theoretical calculation for the two-stage NHTEP has been developed, too. Table 3. gives the model experimental results.

Table 3. The experimental results of two-stage NHTEP

	* gas temper-ature	voltage of charging section	collecting voltage	gas velocity	dust density at inlet	dusting efficency
	℃	V	V	m / s	g/m^3	%
1	0	0	0	0.93	5.48	32.3
2	760	0	0	1.07	5.38	33.8
3	720	0	7,500	1.37	6.32	60.1
4	720	0	9,500	0.94	6.94	65.3
5	720	0	10,000	1.37	5.68	63.6
6	720	0	10,500	0.94	6.21	72.6
7	740	0	10,500	0.70	7.39	77.3
8	760	0	10,500	0.70	8.90	83.6
9	770	0	10,500	1.05	6.80	85.3
10	720	500	7,500	1.37	6.61	78.2
11	720	500	9,000	1.37	3.40	82.9
12	720	500	10,000	1.37	4.83	90.3
13	720	400	10,500	1.30	3.06	93.1
14	760	500	9,000	1.43	3.38	95.9
15	770	300	9,000	0.94	3.38	96.5

* The temperature is that of the gas. The heat loss between the gas flow and the thermocouple tube and between thermocouple tube and thermocouple are not revised. The gas temperature measured by the Heat Spy Infrared Thermometer is about 100℃ higher than that by the thermocouple.

As stated above, the collecting efficiency is related to many factors. We can not study each of them because of limited time. The first, we had made research on the variation of the dusting efficiency against the temperature of emitter and electrric voltage collected. Figure 7 and 8 is a relation curve of dusting efficiency against temperature and vlotage respectively. Figure 7 and 8 show that collection efficiency increases with both temperature and collecting voltage. As we know, there are four forces which act on the charged particles suspended in gas flow, i.e. the gravity, the electricity, the viscosity resistance and the inertress. Generally, the gravity and the inertness can be neglected for fine particles.

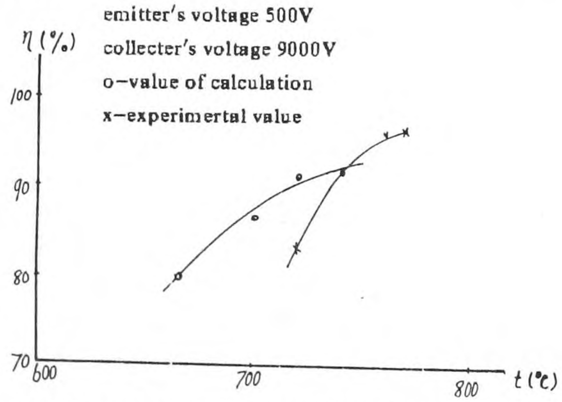


Figure 7. The variation of dusting efficiency η vs temperature T

emitter's voltage 500V
gas temperature 720℃
o-----value of calculation
x-----experimental value

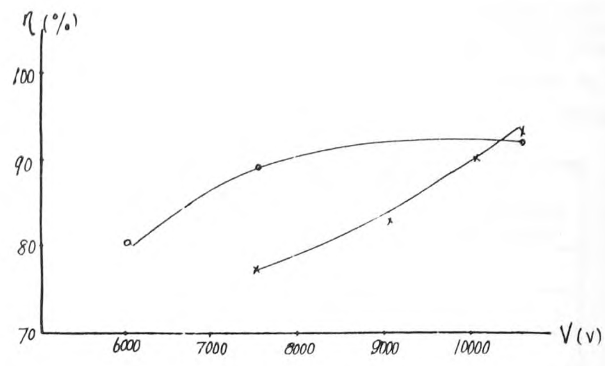


Figure 8 The variaiton of dusting efficiency η vs collecting voltage V

The particles charged will migrate to anode under the act of electric field force, the regular pattern of movement obeys Newton's law of classic mechanics. The migratory velocity is solved by following equation for the fine particles [1]

$$W = qE_p / 6\pi a\eta \tag{3}$$

here W--migratory velocity of charged particles, m / s;

q--charge quantity of particles, c

E_p--electric field strength by collecting electrode, v / m;

a--diameter of particle, m;

η--viscosity factor of air at normal pressure

The equation mentioned above shows that the variation of the migrating velocity is in relation to the charge quantity of particle and the electric field strength of collection section. The higher temperature is, the emitting current will be. As a result, the charge quantity of particles will increase. The migrating vilocity of the particle charged increases with increase of the charge quantity. The increase of the electric field strength will also lead to increase of migrating velocity. We know, the variation of collection efficienct with the migrating velocity is in exponential relation [1].

$$\eta_e = 1 - exp(1 - \frac{A}{V_g} W) \tag{4}$$

here η_e--collecting efficiency;

A / V_g--special collecting area;

W--migrating velocity.

A rise in the migrating velocity is of advantage for increasing the collecting efficiency. The experimental results mentioned above point out that the dusting performance of NHTEP designed by us is conformed with theoretical analyses.

It is shown from Table 2. that the performance of NHTEP has met design requirements. The most collecting efficieency is 96.5%.

Except using all collecting efficiency to express the dusting performance, it can also be expressed by the section efficiency and the characteristic of collected dust.

The divergence of collected dust measured by the method of Bark Centrifugal Classification is shown in Table 4.

Table 4. Scattered degree of collected dust in NHTEP.

diameter μm / wt% / No.	<2	2–5	5–8	8–10	10–20	20–30	>30
1	0.76	22.0	30.0	14.20	26.2	4.70	21.0
2	2.20	21.29	25.44	12.49	26.59	6.34	5.82
3	1.76	29.01	28.80	12.36	21.39	4.42	2.24

It is shown from Table 4. that the dust of medium diameter less than 10μm accounts for 67–72% of the total weight of the dust. Apparently, the capability of collecting fine dust in the NHTEP is quite high.

Table 5. Collected dust quantity in each bin

bin No. / wt.% / No.	1	2	3	4	5	6	7
1	32.8	17.2	26.7	12.9	6.0	2.6	1.7
2	25.2	18.5	23.7	14.1	8.7	5.7	3.6
3	31.0	22.2	22.8	11.9	6.0	3.4	1.7

It is shown from Table 5. that the collecting process in NHTEP is in accordance with the rule of general ESP. Because No.1 bin is set up in charging section,the dust quantity in it is of the most.Its explanation is as follows:

1.All of the charging section use a funnel as bin whose length is more than that of each bin of collecting section.

2.When the dusty gas passes through the charging section,the density of the dust contained in the gas flow is of the largest.

3.There are four arrays of emitter in the charging section from the emitter to the anode, the most near distance to the anode is about 5mm, but extra voltage on the charging section can get 500v,the electric field strength between the most near two electrodes is about 100KV / m,therefore,it is possible that the charging section has several capability of dusting.

It is possible that the boundary effect of electric field will lead to decrease of the dust quantity in No.2 bin, less than that in No.3 bin.

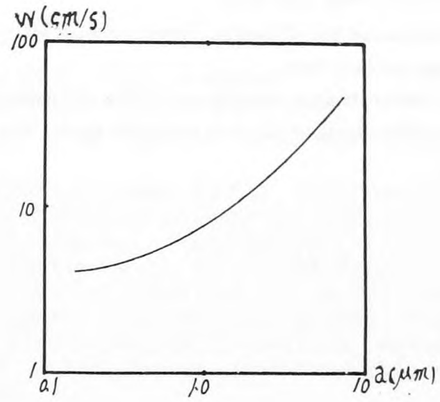
Medium diameter of collected dust in each bin is shown in Table 6.

Table 6. Medium diameter of collected dust in each bin

medium dia.μm / bin No. / No.	1	2	3	4	5	6	7
1	10.5	7.5	6.8	6.7	6.2	6.1	6.1
2	12.5	8.1	7.5	7.3	6.8	7.0	7.0
3	10.7	6.1	6.0	5.6	5.4	5.4	5.4

The diameter of dust particle has a direct effect on the migration velocity, because there exits the difference between increase of charging quantity and that of diameter of particle. The relation of theoretical migration velocity vs diameter of particle is shown in Figure 9.

V = 30kv Vs = 1.36m / s



Figuer 9. The variation of theoretical migration velocity of particle vs its diameter.

Since the migration velocity of the particle increases with the decrease of diameter, the thick particles are collected before fine ones in NHTEP as well as in ESP. It is shown from data in Table 6. that the designed test section conforms with this rule completely. It is necessary to point out that the medium diameter of the collected dust particles is less than that of particles at inlet. The reason is exploding crack of the particles at high temperature while they enter into the charging section. The experimental data in Table 6. again show that the two–stage NHTEP has a capability of collecting fine particles.

4.conclusion

Through a great quantity of experimental studies and theoretical calculation,the two–stage NHTEP has met the designed requirments not only in electrical performance but also in dusting characters. Both the thermal emitting characteristic of emitter and the collecting efficiency of collecting section comform with theoretical analyses. The test section using as experimental investigation has advantages of simple structure, flexibility and convenience for adjustability,etc. Because the emitting current strength mainly depends on the emitting material and the temperature of the emitter and it is not necessary to apply an extra high electric voltage to the emitter in charging section, the insulation problem at high temperature can be solved easily. The cathode can be made of a common plate without a requirement of special structure, thus the field strength in collecting section is more uniform, thus obtaining the profits on collecting dust and simplifying the calculation.

Because NHTEP belongs to a creation in the world and many studies are just started, ther are many technical problems to be solved in the future, for example the study and the development in emitting matterial at high temperature, the problems of vibration and tapping at high temperature to avoid the dust sticking on both anode and cathode, and the preferred design of NHTEP's structure, etc. Also, the analyses of dusting mechanism is quite rough and there exist some misfit between the experimental data and the theoretical calculation results.

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